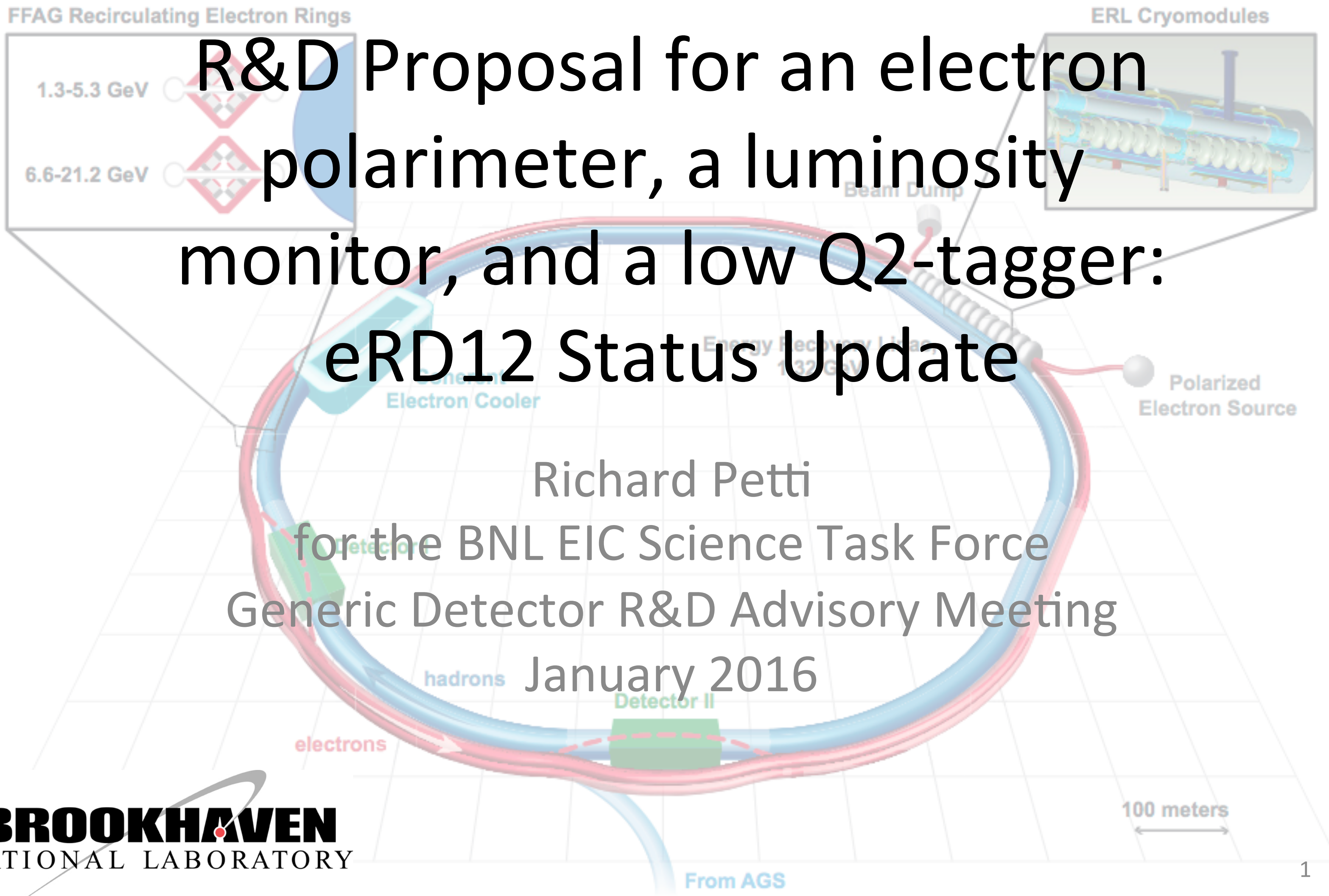
R&D Proposal for an electron polarimeter, a luminosity monitor, and a low Q2-tagger: eRD12 Status Update

Richard Petti

for the BNL EIC Science Task Force

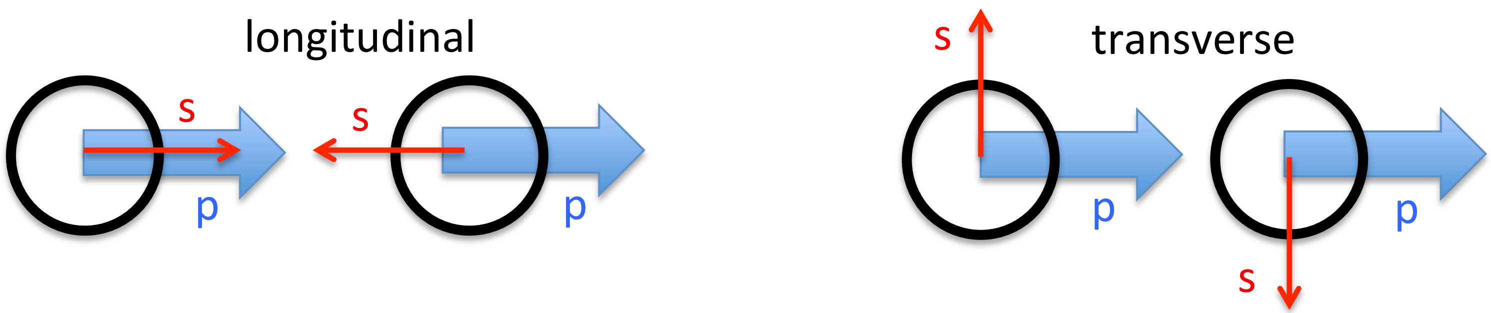
Generic Detector R&D Advisory Meeting

January 2016



BROOKHAVEN NATIONAL LABORATORY

Electron Polarimetry: Current Goals



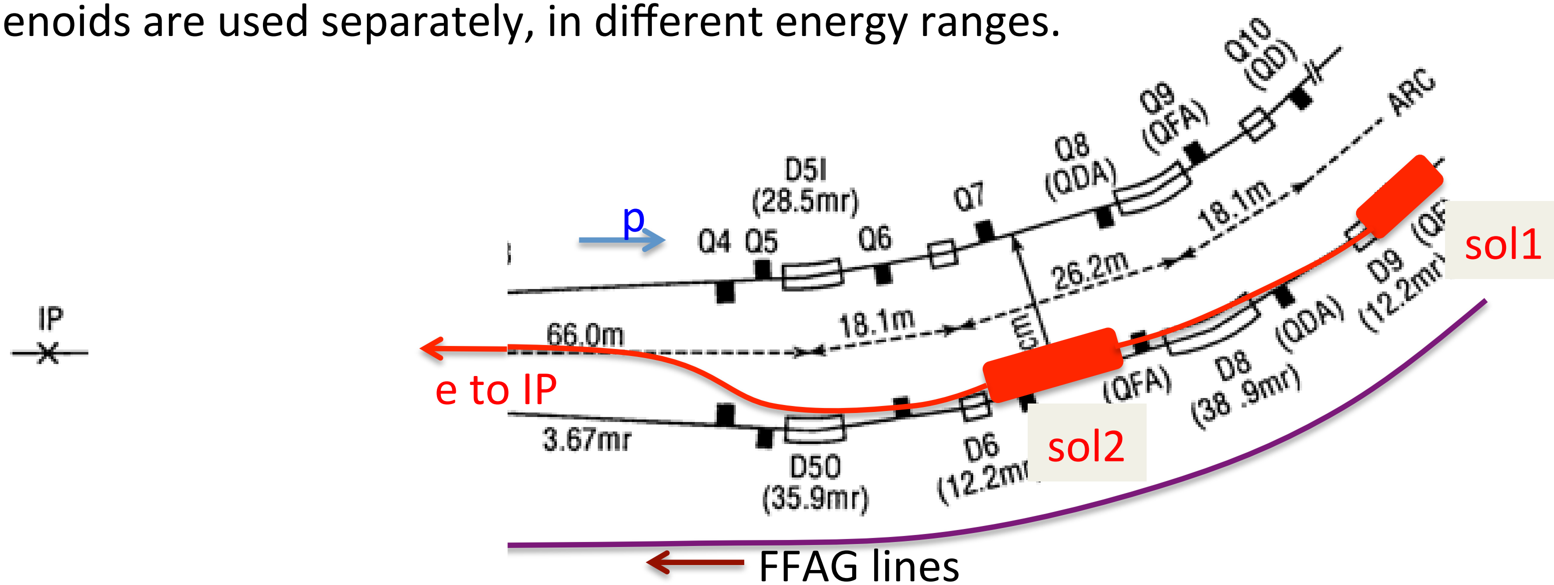
- Determine all requirements on the polarimeter system
- Find a suitable location in the eRHIC tunnel for a polarimeter system
- Develop a system that can measure the full polarization vector of the electron beam
  - Currently investigating setups that can measure a purely longitudinal (transverse) polarized beam
  - Will bring everything together for full polarization vector orientation
- Consider uncertainties in measurement
- Consider the different requirements for each machine design
  - ring-ring
  - linac-ring design

Electron Beam Polarimetry

- Basic requirements:
  - uncertainties less than 1%
  - placement before the interaction point
  - placement after the spin rotators
  - measure during normal operation (non-destructive)
  - luminosity high enough to track polarization on timescale of depolarizing effects, i.e. O(minutes)
  - monitor the polarization for each cathode producing the electrons (linac-ring option) or bunch (ring-ring option) several times per fill
  - measure both longitudinal and transverse spin components

Spin Rotators in the Tunnel

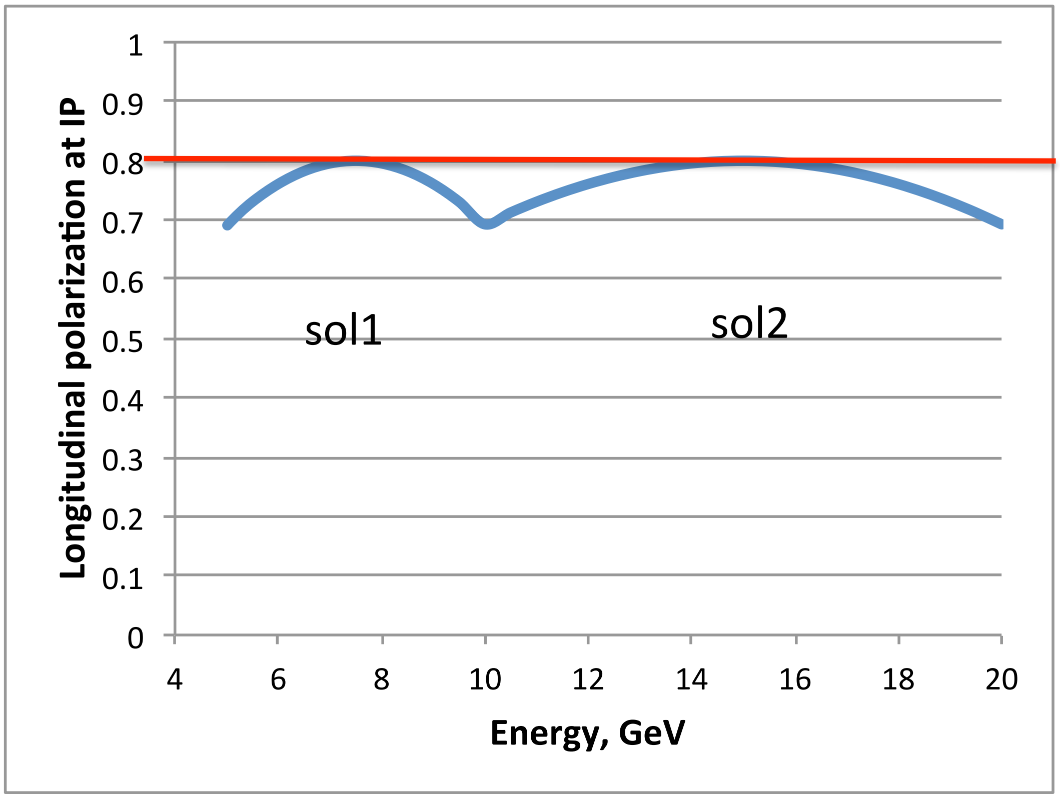
Each solenoid rotates spin by 90 degrees.
Solenoids are used separately, in different energy ranges.



	Operation range, GeV	Field integral range, T*m	Orbit angle from IR	Area of RHIC tunnel	Solenoid length for 7T field
Sol1	5-10	26-53	92 mrad	D9-D10	7.6 m
Sol2	10-20	52-105	46 mrad	D6-Q8	15 m

Expectations for the effectiveness of the spin rotators

Assuming 80% polarization from the source.



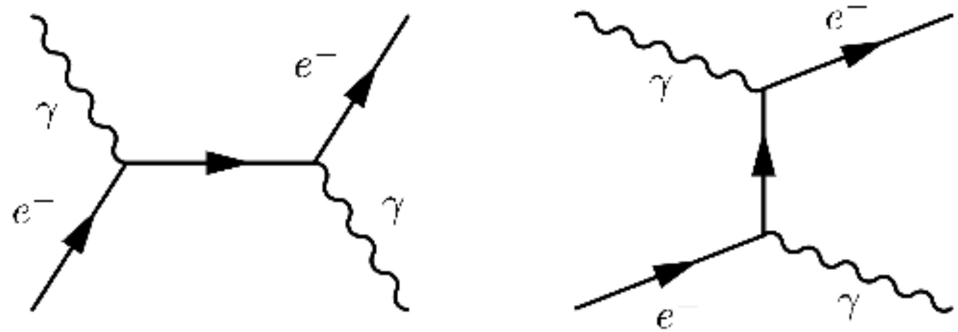
5-10 GeV:
Only sol1 solenoid is powered
sol2 field = 0

10-20 GeV:
Only sol2 solenoid is powered
sol1 field = 0

possible to improve design by operating both together

shows need for a transverse polarimeter along with the longitudinal

Compton Backscattering for Polarimetry



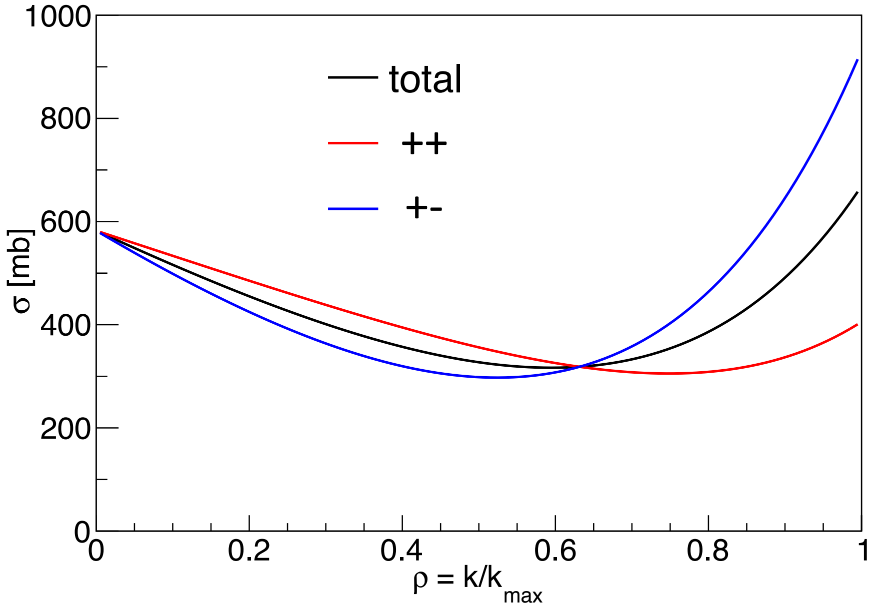
- Compton events produced by shining a laser on the electron beam
- Scattering dependent on the helicity of the photon and the spin direction of the electron

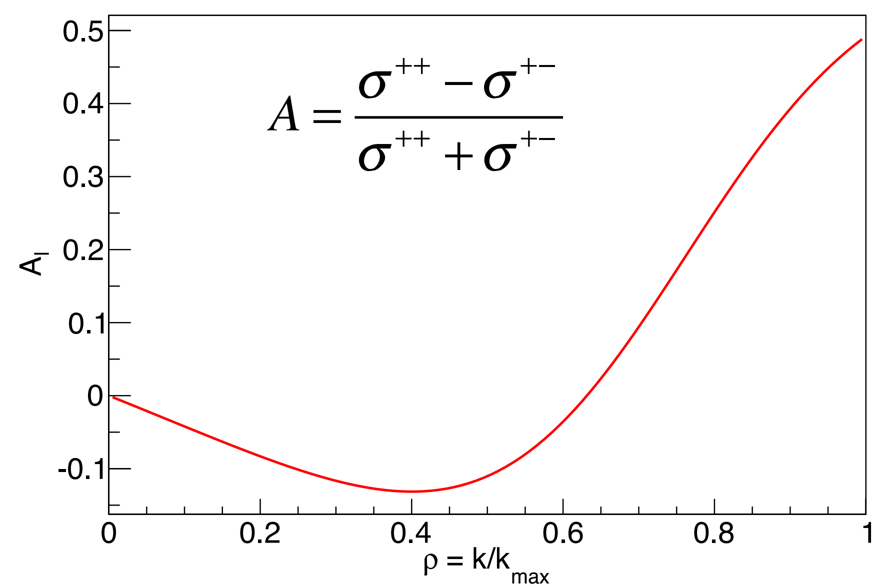
$$A = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} \qquad\qquad A_{\mathrm{exp}} = P_e P_\gamma A_\ell$$

- Measure asymmetry via the scattered photon or electron (or both)
- Cross sections calculated analytically in QED

Compton Scattering with a Purely Longitudinally Polarized Beam

- for 20GeV electron beam and 2.33eV laser
- expressed as a function of photon energy scaled by the Compton edge
  - max photon energy = 8.33GeV (Compton edge) for this setup



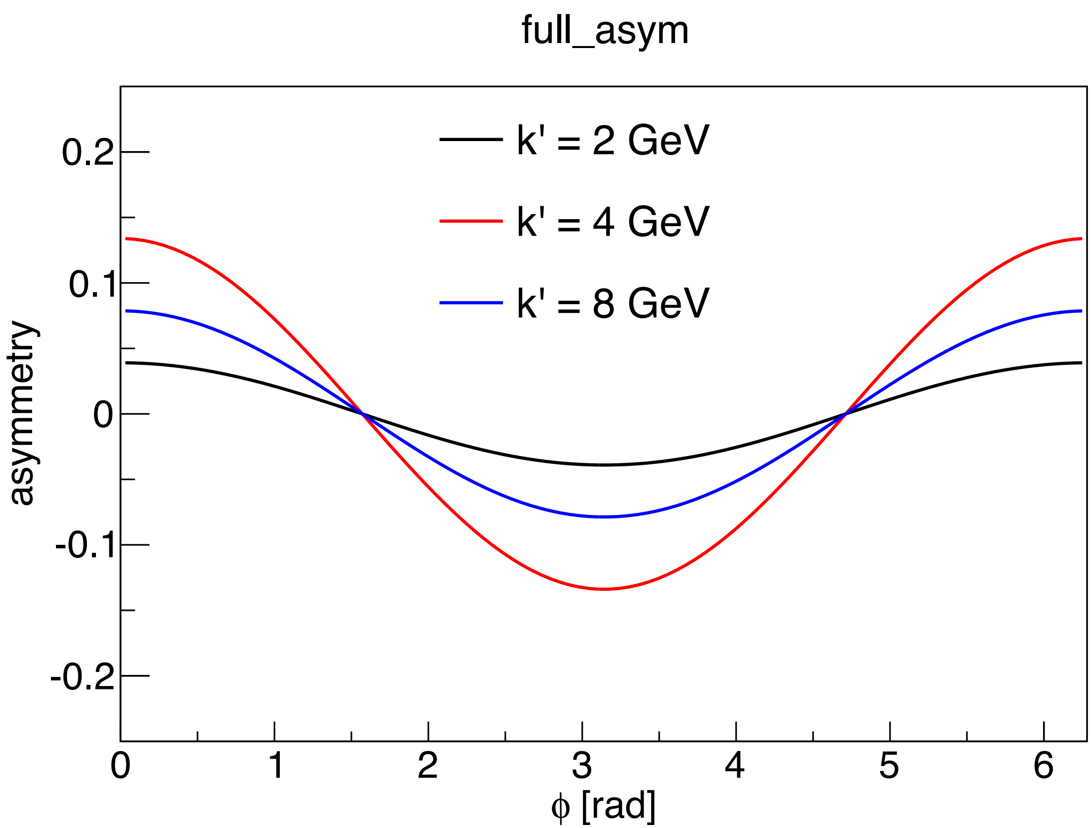


- ρ is the energy of the scattered photon relative to the max allowed energy from kinematics

need to measure photon energy for **longitudinal** polarization

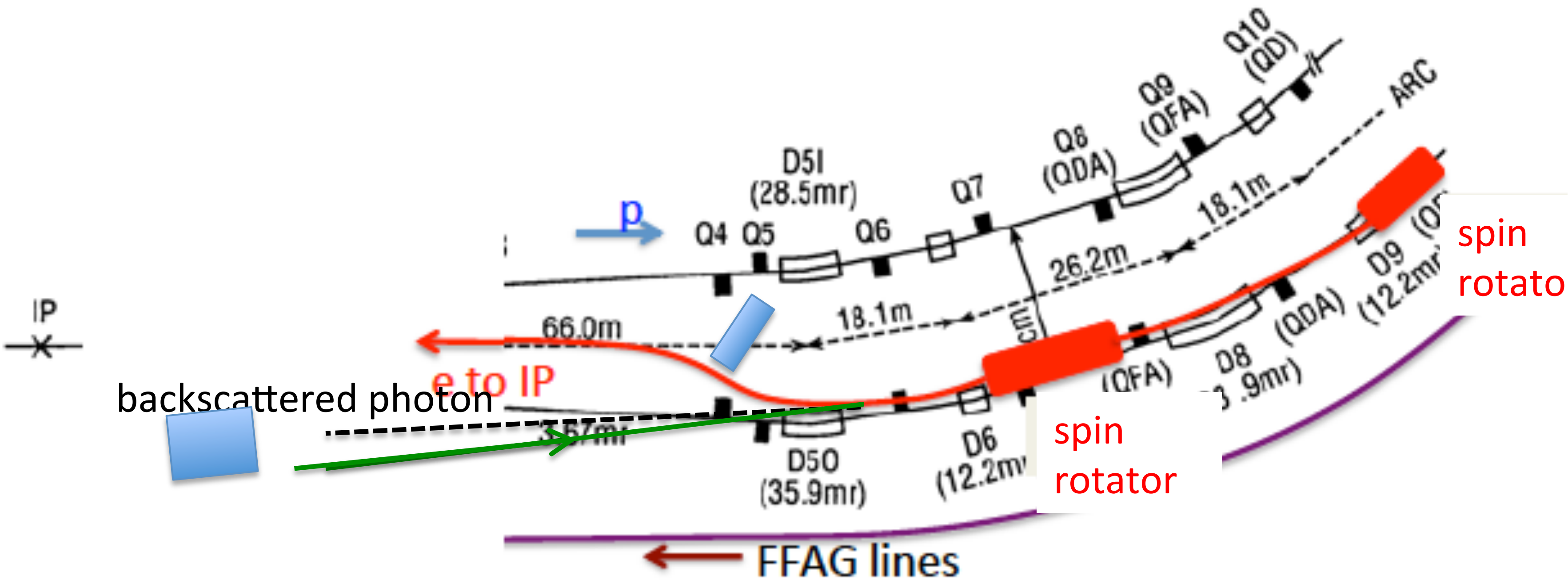
Compton Scattering with a Purely Transversely Polarized Beam

- for 20GeV electron beam and 2.33eV laser



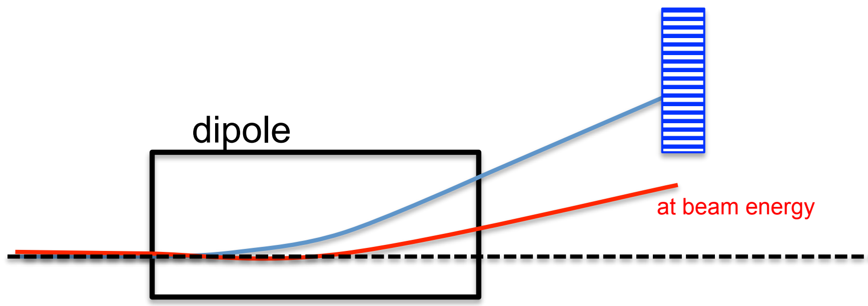
need to measure photon **energy** **and** **position** for **transverse** polarization

Placement of the polarimeter in the RHIC tunnel



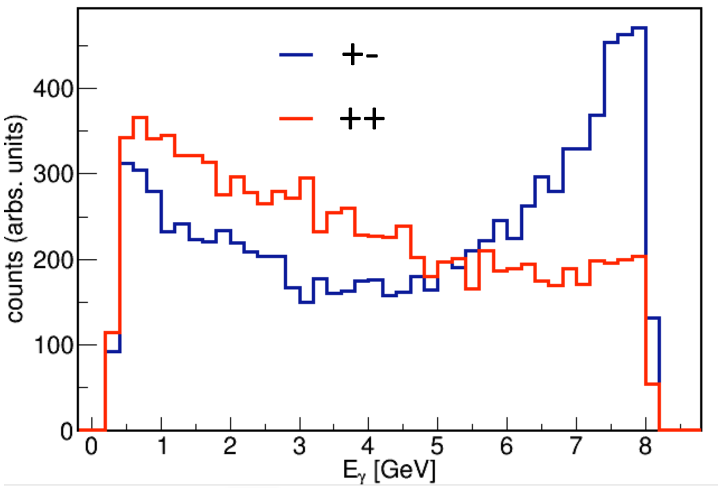
- general schematic shown
- detailed lattice design in this region does not yet exist

Polarimeter simulations

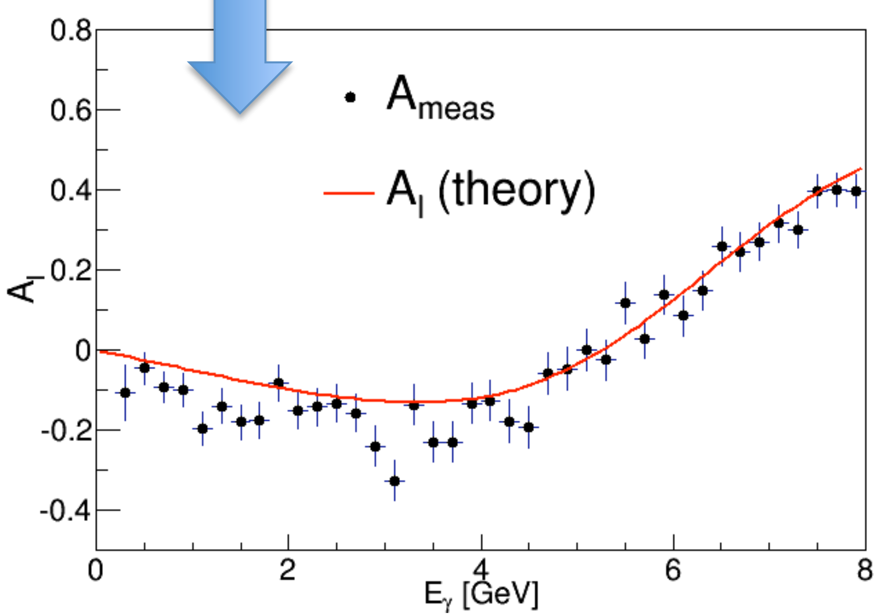


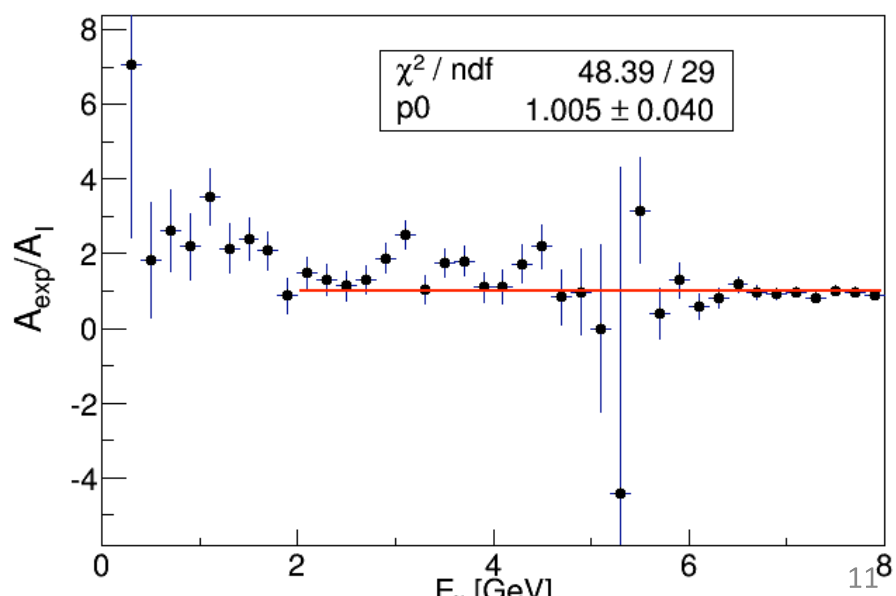
- Due to lack of detailed lattice setup, we make some simple assumptions based on guidance from CAD
  - place detector downstream of a 2m long dipole magnet of B = 0.2T (possibly representing the first magnet making the orbit shift, see fig. on previous page)
- Simple setup for now to get analysis tools off the ground
  - use EicRoot
  - place calorimeter for photon measurement
  - place strip detector for electron measurement
  - currently can extract the longitudinal polarization from collisions fed into the simulation

Simulation on measuring the longitudinal polarization (I)



- first focus on measuring the scattered photon
- simulation operation in "single photon mode"
- feed in simulated events based on Compton distributions
  - input polarization fraction 100%
- calorimeter towers of size 2.5x2.5x20cm, $PbW0_4$ crystal
- full reconstruction with clustering
- measure the energy spectrum for each collision mode

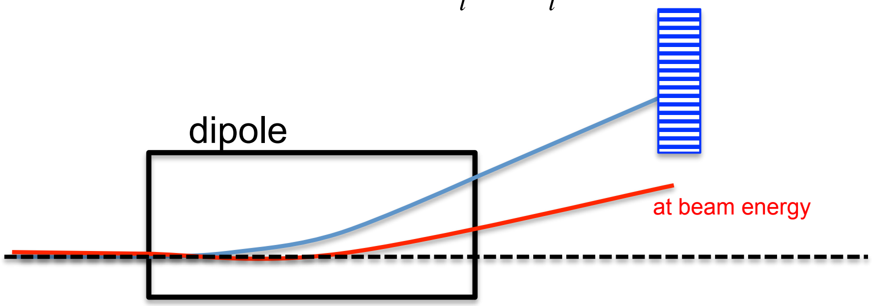


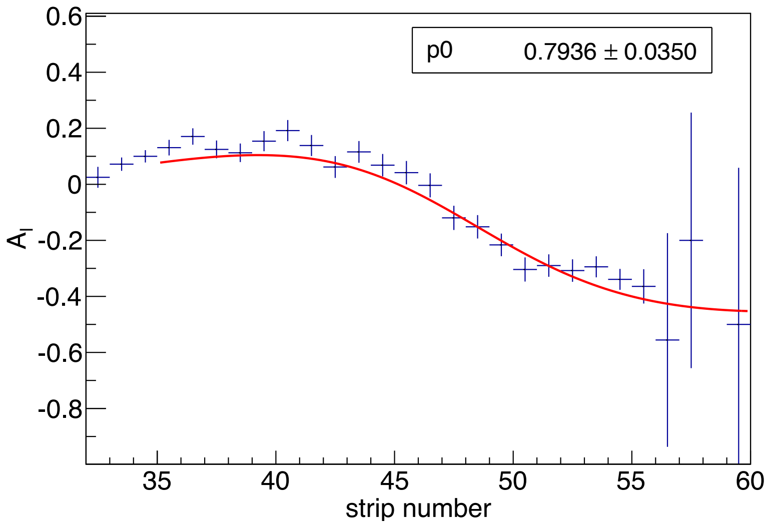


Simulation on measuring the longitudinal polarization (II)

- measuring the scattered electron
- feed in polarization fraction of 80%
- use the dipole as a spectrometer
  - convert the energy distribution to a position distribution on the face of the strip detector
  - can calculate the counting asymmetry of electrons in each individual strip
  - compare measured asymmetry to calculation from QED
  - the following implements a 0.5m drift with a 250um strip detector

$$A_{\exp,i} = \frac{n_i^+ - n_i^-}{n_i^+ + n_i^-}$$



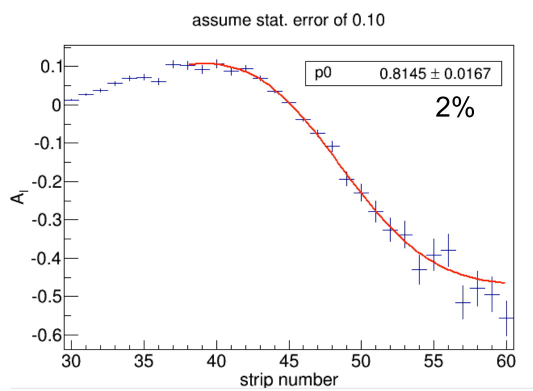


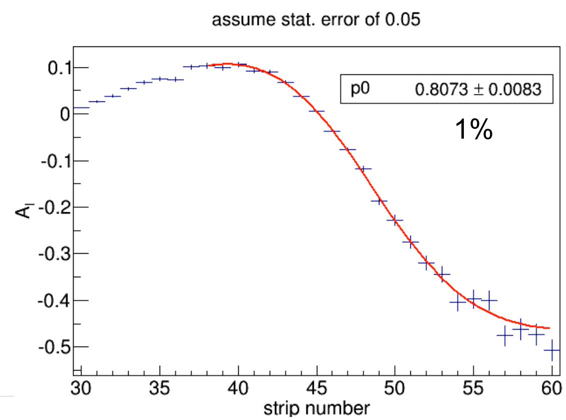
Further studies on longitudinal polarimeter with electrons

- investigate statistics needed to perform a 1% level measurement
  - will feed into laser choice
  - will feed into optimization detector geometry
  - here we make one choice and investigate
  - 0.5 meter drift distance, 250um strip width

How does statistical precision affect polarization precision?

- generate the asymmetry distribution based on the theoretical asymmetry
  - smear each point by the specified uncertainty
  - do the fit and extract the polarization with its uncertainty





Need roughly 20,000 events for each spin configuration for 1% precision in this setup

- uncertainty on polarization scales with analyzing power

$$\delta P = \frac{\delta A_{\exp}}{A_\ell}$$

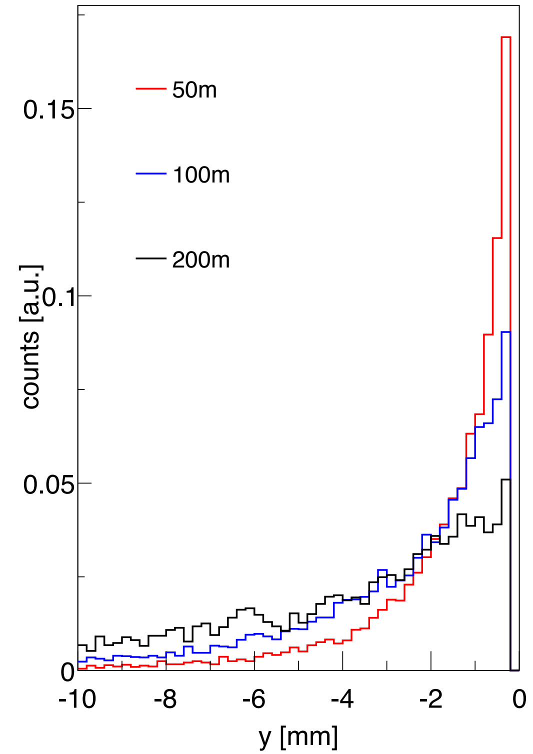
Summary on Measuring Longitudinal Polarization

- Simulation set up for measuring longitudinal polarization using either scattered photon or electron
- Investigated the statistics needed for a good measurement
  - next step is to use this information to guide laser system choices
- Code base written to extract polarization from either of these measurements

Measuring Transverse Polarization

- measure the position asymmetry as a function of energy
- electrons can have both a horizontal and vertical transverse spin component after spin rotators
  - horizontal component gives rise to left-right asymmetry
  - vertical component gives rise to a top-bottom asymmetry
  - need to measure the full angle of the photon
- imagine a finely segmented calorimeter proceeded with a position sensitive silicon detector
- still a work in progress…

y-position of photon at face of detector placed at varying distance

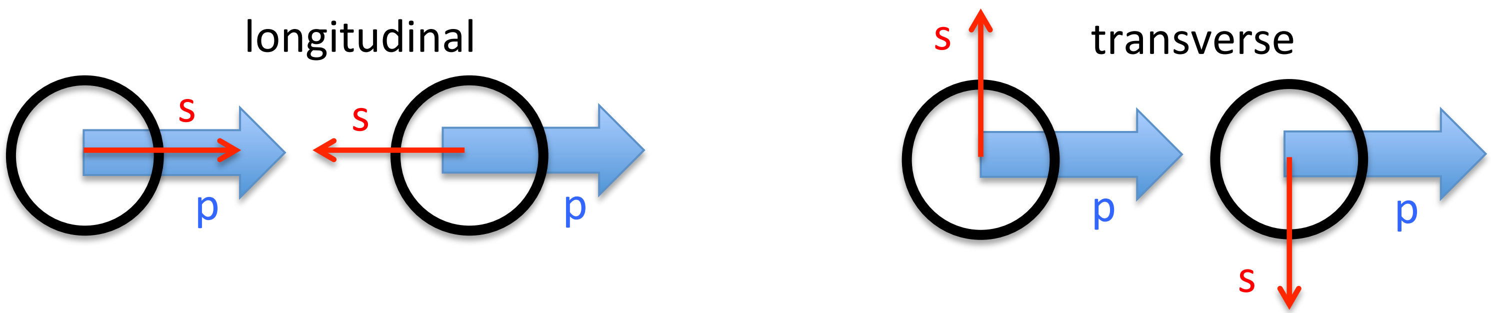


need to optimize the resolution to resolve the shape of the distribution

What next?

- Further develop transverse polarization measurement scheme
- Integrate the two methods of longitudinal and transverse polarization into one device
- Pursue studies related to choice of laser system
- Continue to optimize detector configuration in tunnel
- Look into higher order corrections to the QED calculation of Compton scattering
- Background studies
- Study systematic uncertainty contributions
- Continue to follow machine design for more realistic setup
  - holding bi-weekly IR design meetings with CAD and magnet division
- Redo previous studies with the setup for the ring-ring design
  - current studies all deal with linac-ring setup

Summary



- Determine all requirements on the polarimeter system
- Find a suitable location in the RHIC tunnel for a polarimeter system
- Develop a system that can measure the full spin vector of the electron beam
  - Currently investigating setups that can measure a purely longitudinal (transverse) polarized beam
  - Eventually will bring everything together for a full spin vector orientation measurement
- Consider uncertainties in measurement
- Consider the impact of the choice of machine design
  - ring-ring
  - linac-ring design

Backups

The equations from QED for Compton Scattering

total cross section: $$\frac{d^2\sigma}{d\rho d\phi} = \frac{d^2\sigma_0}{d\rho d\phi} \mp P_e P_\gamma \left(\cos\psi \frac{d^2\sigma_1}{d\rho d\phi} + \sin\psi \cos\phi \frac{d^2\sigma_2}{d\rho d\phi} \right)$$

unpol. contrib.: $$\frac{d^2\sigma_0}{d\rho d\phi} = r_0^2 a \left[\frac{\left(\rho(1-a)\right)^2}{1-\rho(1-a)} + 1 + \left(\frac{1-\rho(1+a)}{1-\rho(1-a)} \right)^2 \right]$$

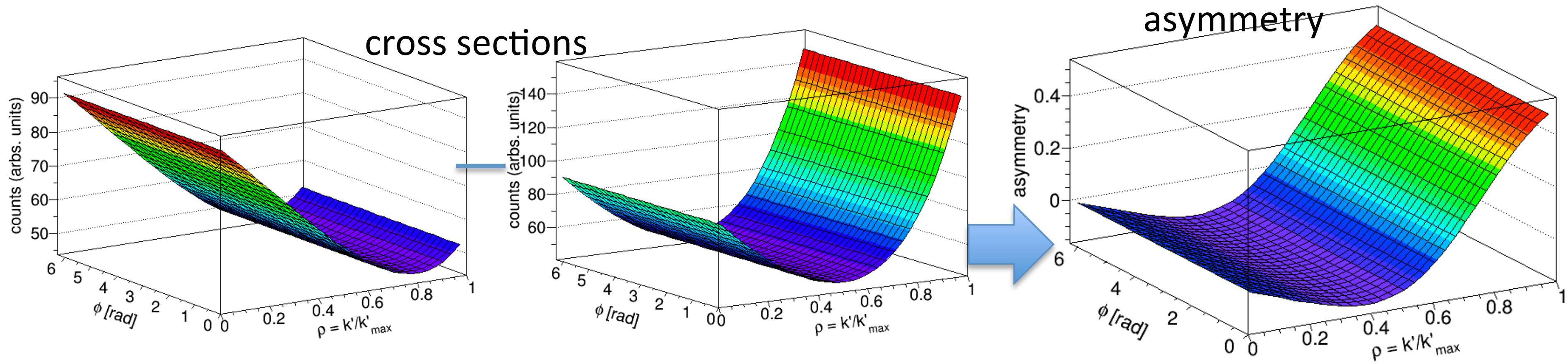
long. pol. contrib.: $$\frac{d^2\sigma_1}{d\rho d\phi} = r_0^2 a \left[\left(1-\rho(1+a)\right) \cdot \left(1 - \frac{1}{\left(1-\rho(1-a)\right)^2} \right) \right]$$

trans. pol. contrib.: $$\frac{d^2\sigma_2}{d\rho d\phi} = r_0^2 a \left[\rho(1-a) \frac{\sqrt{4a\rho(1-\rho)}}{1-\rho(1-a)} \right]$$

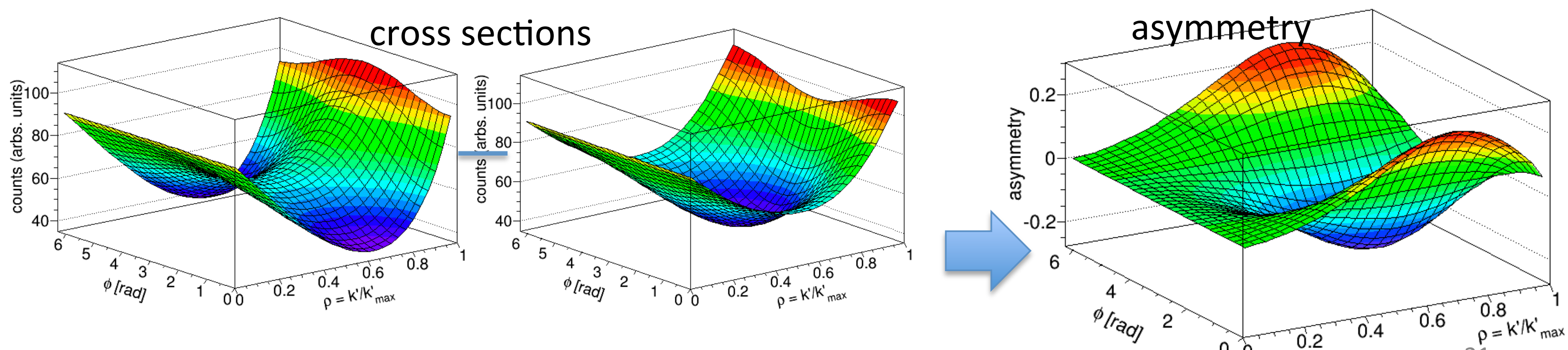
- ψ is the angle of the spin vector to the direction of particle momentum
- Φ is the azimuthal angle in the lab frame
- ρ is the scattered photon energy (relative to the Compton edge)
- a is a kinematical factor related to the electron beam energy and laser photon energy

Compton Scattering for polarimetry

Longitudinally polarized 20 GeV beam with 2.33 eV laser



Transversely polarized 20 GeV beam with 2.33 eV laser



- associated equations can be found in the backups

Measuring Transverse Polarization

- setup to measure the photon
- start by recreating setup via the TPOL at HERA
- install a downstream calorimeter that is segmented into upper and lower halves
- look at the difference in energy deposited between the upper and lower halves to get a handle on the position of the photon

$$\eta = \frac{E^{up} - E^{down}}{E^{up} + E^{down}}$$

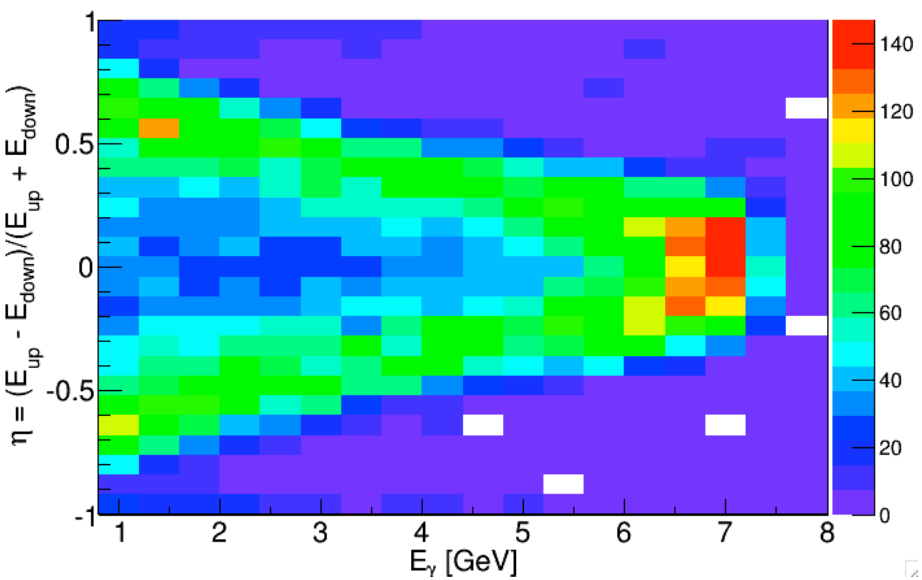
- can consider placing a pre-shower or a very finely granulated calorimeter in the future, but to get an initial setup, we first consider the simplest approach

Distributions from the simulations

- have simulated events processed through EicRoot
- still developing software to extract the polarization from the distributions
  - determine eta – y mapping (in software here)
  - extract polarization via difference in y distribution as a function of E

$$\Delta Y(E_\gamma) = \frac{\langle Y\rangle_L - \langle Y\rangle_R}{2} = P_Y \Delta S_3 \Pi_Y(E_\gamma)$$

Left + Right



Left - Right